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Farming Systems: Impact on Water Quality

Management Systems Evaluation Areas (MSEA) Progress Report 1994

Report of the MSEA Program of the—

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Water Quality Problems in the Midwest

The Midwestern United States is the location of the world's most intensive agricultural production system, which tends to use a large amount of agricultural chemicals. Over 80 percent of the corn and 70 percent of the soybeans produced in the United States are grown in the Midwest. To produce these crops requires 58 percent of the nitrogen fertilizer (EPA 1990) and over 60 percent of the herbicides (Gianessi and Puffer 1990) used in the United States. These agricultural chemicals are applied on more than 96 percent of the Midwest land area planted to corn and soybeans (USDA 1993). In 1992, the top five pesticides used in corn production in the United States were atrazine on 69 percent of the corn acres planted, metolachlor on 30 percent, alachlor on 27 percent, dicamba on 21 percent, and cyanazine on 20 percent (USDA 1993). For soybeans, the top five pesticides in use for 1992 were trifluralin on 35 percent, imazethapyr on 29 percent, pendimethalin on 21 percent, imazaquin on 18 percent, and chlorimuron-ethyl on 17 percent (USDA 1993). All these pesticides are herbicides used for weed control.

There have been several efforts in recent years to measure the quality of the surface and ground waters of the United States. The U.S. Geological Survey (USGS) sampled aquifers within 15 meters (50 feet) of the land surface throughout the Midwest and screened each sample for detection of any herbicide and nitrate-nitrogen (Burkart and Kolpin 1993). Herbicides were found in 24 percent of the 579 wells sampled. The most frequently detected compound was the atrazine metabolite deethylatrazine followed in order by atrazine, deisopropylatrazine, prometron, metolachlor, alachlor, metribuzin, simazine, and cyanazine. The reported concentrations for all compounds were less than 0.5 µg/L (1 microgram per liter equals 1 part per billion) with a few samples exceeding the 1.0 µg/L (1 ppb) maximum contamination limit (MCL) (Burkart and Kolpin 1993). Herbicides found within the samples were among those extensively used throughout the Midwest. In this study, the herbicide prometron was found in wells sampled near residential land or golf courses, indicating that herbicides used for nonagricultural purposes could also enter the aquifers.

Nitrate has been found in shallow ground water samples in the Midwest. Burkart and Kolpin (1993) found nitrate-nitrogen above the 10 mg/L (1 milligram per liter equals 1 part per million) MCL in 6 percent of their samples. Detections above 10 mg/L (10 ppm) vary among the Midwestern States. Madison and Burnett (1985) found that 6.4 percent of the 123,656 wells sampled throughout the Nation had nitrate concentrations greater than 10 mg/L and 13 percent between 3 mg/L and 10 mg/L. Nitrate moves through the soil profile with the percolating water and can leach below the root zone unless taken up by plants. Mueller et al. (1993) found that nitrate concentrations in the surface waters of the Midwest were related to streamflow at the time of sampling, acreage of the basin in corn, acreage in soybeans, and density of both cattle and human populations.

Recent herbicide monitoring efforts at nine different surface water sites within the Mississippi River Basin by the U.S.Geological Survey for 1989 and 1990 revealed large amounts (pounds of herbicides) during the first runoff after herbieide application. Atrazine was detected in 100 percent of the surface water samples for the April 1991 through March 1992 period (Goolsby and Battaglin 1993). The average concentrations of atrazine before planting and application were less than 1 µg/L and increased to 3.8 µg/L after planting in the 132 streams sampled during this time. The atrazine concentrations in the surface waters were related to the increase in streamflow. The amount of atrazine lost from the Mississippi River basin to the Gulf of Mexico is small and represents less than 3 percent of the amount applied within the basin. Nitrate losses, however, may represent closer to 15 percent of the amount applied within the basin.

Ground water is the primary source of domestic water in most of the Midwest. Surface water supplies from lakes and reservoirs account for less than 10 percent of the drinking water within these States. The MSEA (Management Systems Evaluation Areas) program was developed to understand the linkages between farming practices and water quality in the Midwest by studying the system from application to transport.

Herbicide and nitrate detections in surface and ground water have prompted concern about the pathway of movement from different farming practices in the surface and ground waters of the Midwest. The MSEA program was formed with a goal to identify and evaluate agricultural management systems that can protect water quality in the Midwest. This progress report will describe the efforts of this program to understand how different farming practices affect surface and ground water quality.

Management Systems Evaluation Areas

MSEA brings together scientists, educators, and technical assistance specialists from a variety of public sector and academic settings in an integrated, multiagency program that is built on unity of purpose. The research is cooperatively conducted by Federal, State, and university scientists; planning, evaluation, and oversight are managed by interagency groups.

The MSEA program is a cooperative endeavor among the U.S. Department of Agriculture's Agricultural Research Service (ARS), Cooperative State Research, Education, and Extension Service (CSREES), and Natural Resources Conservation Service (NRCS); State agricultural experiment stations (SAES); and the U.S. Geological Survey. The U.S. Environmental Protection Agency (EPA) has become a participant in the MSEA program through the MASTER (Midwest Agrichemical Surface/Subsurface Transport and Effects Research) project. Several State agencies are involved in each of the participating States throughout the Midwest. Five projects with a total of 10 sites are locations (fig. 1) within the MSEA program.

Within USDA, leadership for the MSEA program is provided by ARS and CSREES in close cooperation with SAES as well as NRCS. ARS and CSREES are conducting a major portion of the research on developing better techniques and methods for managing land use, soil, water, nutrients, and pests. Investigators within SAES and other university scientists, in cooperation with ARS, conduct research to address needs for different management systems throughout the Midwest. ARS, CSREES, SAES, and NRCS work together to make the results available quickly to other agencies. The USGS Mid-Continent Herbicide Initiative provides expertise on geology, hydrology, and ground water movement. EPA, as part of the MASTER project, leads the effort to assess agricultural effects on ecosystems and ecosystem protection.

The MSEA program was developed around six general objectives to address the program goal. The objectives of the program are to:

- Measure how prevailing and modified farming systems affect the content of nutrients and pesticides in ground and surface waters.

At the Walnut Creek watershed in central Iowa, technician samples surface runoff and water flowing out of tile lines under farm fields to measure pesticide and nitrate levels (92BW1863-25).

- Identify and increase understanding of the factors and processes that control the fate and transport of nutrients and pesticides.

- Assess how nutrients, pesticides, and agricultural production practices affect ecosystems associated with agrieulture.

- Assess projected benefits and costs of implementing modified farming systems in the Midwest.

- Evaluate the social and economic effects of modified management systems.

- Transfer appropriate technology for use by the farming community.

MSEA brings together the scientific expertise needed to address concerns about current farming systems and non-point-source pollution through a variety of approaches and at several sites. Field studies are conducted at many sites to address these objectives. Combined with detailed laboratory studies directed toward understanding the mechanisms of nitrogen and pesticide movement and evaluation of techniques for determining the nutrient status of soil and plants, the MSEA program blends the basic and targeted research toward better agricultural systems.

Since the MSEA program has the capability to study the entire system, separate research projects address a wide range of issues related to surface and subsurface water quality. Some examples are:

- Farming systems are customized to regional and local conditions. Unique combinations representing the most appropriate farming systems are evaluated at many sites.

- Management systems are compared to determine which are most environmentally sound. Water samples are collected in all parts of the hydrologic system and analyzed for alachlor, atrazine, metolachlor, metribuzin, and other herbicides, as well as nitrate and phosphorus. These are the most common agricultural chemicals used in the production of corn and soybeans in the Midwest.

- Data quality is a high priority for the program. Rigorous protocols have been developed for collecting samples and recording data. Analyses of all water quality samples within the MSEA program are verified by an independent laboratory.

- Models and decision-aid systems enable scientists to better account for processes that take place when water moves through the soil or runs off the surface. Some of the processes evaluated include: rates of waterflow through macropores, effects of tillage and residue cover on movement of water and chemicals, dynamics of herbicide degradation, nitrogen cycling and transformations, and evaluation of plant growth and water uptake patterns.

- Effects of agricultural practices on ecosystems are tracked to enable prediction of how agricultural practices affect ecological resources. Information on the fate and transport of agricultural chemicals (fertilizers and pesticides) in subsurface and surface waters is integrated with information on how agricultural practices affect entire watersheds.

- Socio-economic factors such as profitability, effects on vendors, convenience, and economic incentives play an important role in the choice of management practices. Farm-level evaluations of modified farming systems are conducted, not only to assess how well they protect surface and ground water, but also to learn whether they are accepted by farmers in different areas.

MSEA Research Locations

Research is conducted at 10 sites (fig. 1) from five different projects within the MSEA program. These sites cover a wide range of the soils and hydrogeology of the Midwest. Table 1 describes soil and aquifer materials for the sites.

Sites where intensive research is being conducted represent a wide range of soils and aquifer materials, about 20 percent of the land area and aquifer materials of the Midwest. Aquifers represented in the MSEA program are significant sources of water for public use and consumption (USGS 1984). More than 70 percent of the population of Iowa, Minnesota, Nebraska, South Dakota, and Wisconsin are served by aquifers studied in this program. Alluvial valley aquifers supply water for major cities in Indiana, Iowa, Missouri, Nebraska, and Ohio. Nutrients and pesticides will respond differently at each of these sites. Three sites involve watershed-scale research: Treynor and Walnut Creek, Iowa, and Goodwater Creek, Missouri. The other sites are field-scale research areas located within a portion of a watershed.

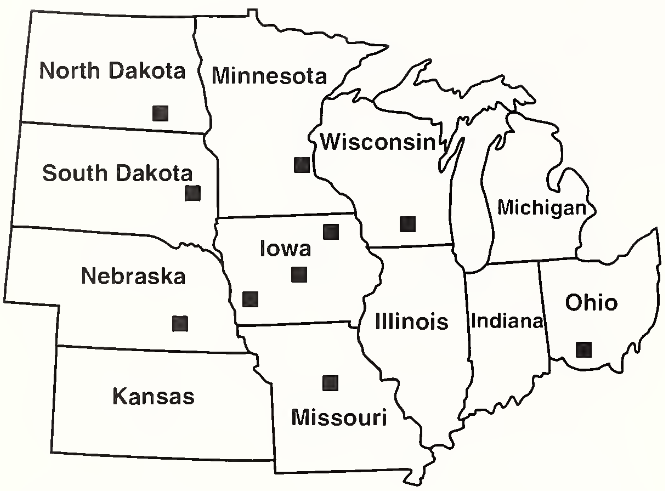


Figure 1. MSEA sites.

Organic carbon content of the soil is a major factor in movement of nutrients and herbicides through the plant root zone and into the vadose zone (depth of soil between where the plant roots grow and the ground water table). Organic carbon content ranges from less than 1 percent in the sandy soils of the Anoka sand plain to over 4 percent in the glacial till soils of central Iowa. The NRCS National Soil Survey Laboratory has characterized each of the sites for its hydraulic properties to quantify the rate of water movement through the soil, the soil structure and texture, and the general soil characteristics. These characterizations help relate information collected in these studies to other sites in the Midwest.

Table 1. Locations and descriptions of the soil and aquifer materials for MSEA sites

Location	Surface Soil Material	Aquifer Material	Aquifer Name	Depth to Aquifer
Treynor, IA	Silt loam	Loess/sandstone	Loess/Pennsylvanian	30 m
Nashua, IA	Loam	Carbonate rock	Silurian-Devonian	60 m
Walnut Creek, IA	Clay loam	Sand and gravel/sandstone and carbonate rock	Skunk River Alluvium/ Mississippian	100 m
Princeton, MN	Loamy sand	Loamy sand over sand	Anoka Sand Plain	3-4 m
Oakes, ND	Sandy loam	Loamy sand to gravel	Oakes	3 m
Aurora, SD	Silt loam	Gravel	Big Sioux	4-7 m
Arena, WI	Sand	Sand	Wisconsin River Sand Plain	3 m
Centralia, MO	Silt loam with a claypan	Silty clay	Glacial Drift	0.5-5 m
Shelton, NE	Silt loam	Silt, sand, gravel	Quaternary Deposits	4-5 m
Piketon, OH	Silt loam or silty clay loam	Sand and gravel	Scioto River Valley	2-3 m

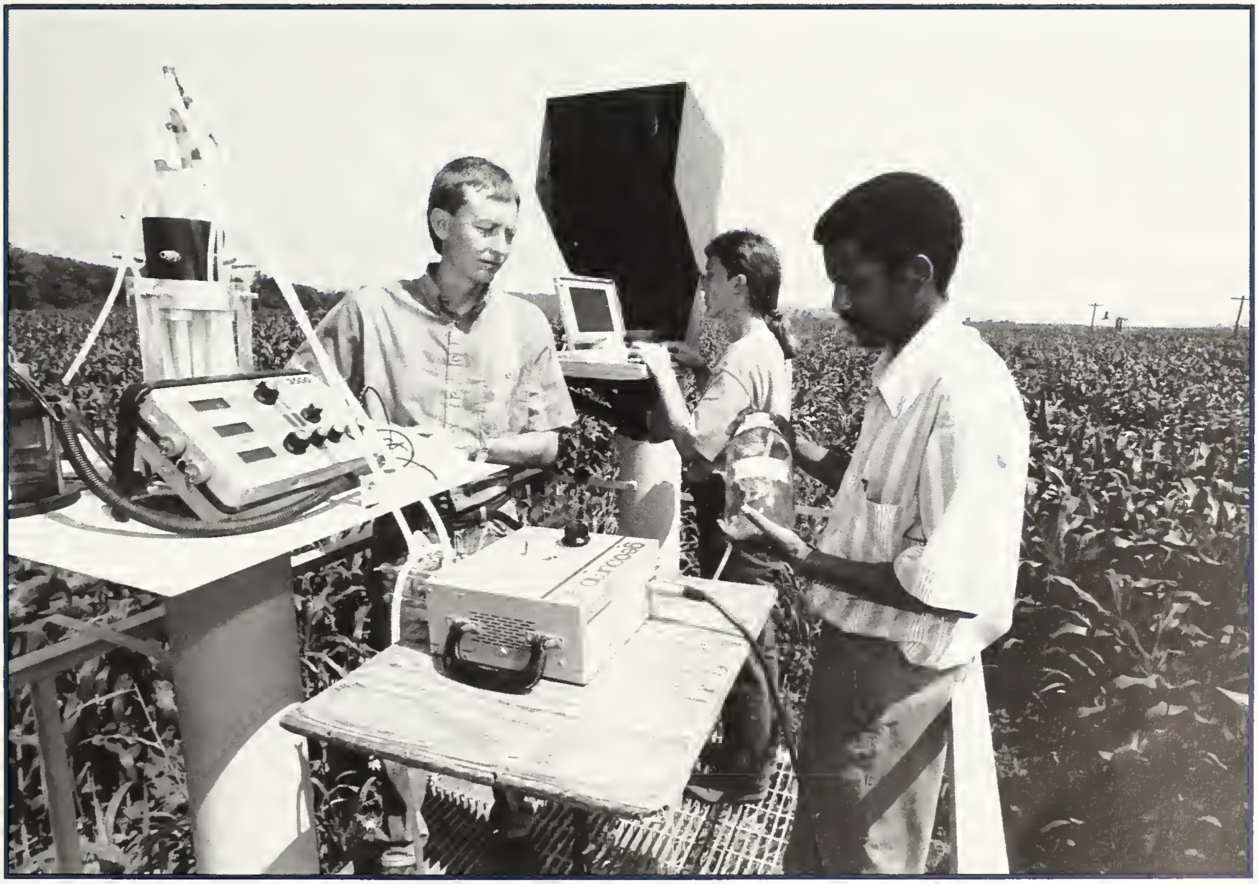
Monitoring Activities

Monitoring activities began at all sites in 1990, and the installation of equipment was completed in 1991. Extensive networks of shallow and deep wells from which water samples are collected quantify the movement of the herbicides and nitrate below the root zone. Shallow lysimeters placed within several farming systems intercept free water moving in preferential flow paths to characterize herbicide and nitrate movement around and through the root systems of crops during the growing season. A series of single-port or multiport wells installed at each site permit investigators not only to collect a sample for analysis, but also to determine the rate and direction of water movement to and within the aquifer. Analyses of tritium, nitrogen species, and minerals within the wells are used to determine the age of the water at different depths and the processes influencing water quality as water moves through the vadose zone to the aquifer.

Considerable effort has been directed toward developing procedures for the monitoring of herbicides and nitrate in the ground water. MSEA investigators have worked to ensure that the data collected from each site and farming practice represent the conditions under which the study was conducted, and samples are collected according to strict protocols. Laboratory methods for determining concentration of herbicides and nitrate are continually checked against an external laboratory and among sites to maintain a high degree of confidence in the results.

At the watershed sites, surface runoff is collected from both fields and plots, and stream monitoring permits an assessment of the surface water quality from an agricultural area. Soil water conditions measured in the root zone permit investigators to understand the dynamics of the water balance. These measurements allow for estimating water use by the different farming systems and evaluation of waterflow models that estimate how nutrients and herbicides move through the root zone during the year.

Crop grain yield and weed control are two primary factors used to determine response to each farming system. Nitrogen contents of the plant and soil are measured in each farming system to determine how it can be more effectively used by the crop. Several techniques to monitor nitrogen requirements are being evaluated over the different locations to provide potential methods for on-farm application.



At an Ohio site near Piketon, scientists and graduate students accumulate information to monitor nutrients and pesticides in multiport and conventional wells (93BW1679-34).

Farming Systems Within the MSEA Program

A corn-soybean rotation is the primary cropping system of the Midwest and is being examined at all five MSEA projects. Variations of nitrogen management and weed management are evaluated at the different sites; however, sites differ because local practices are dictated by climate, soil, landscape, and tillage practices. At each site, an effort was made to use a realistic system practiced by the farmers as a basis for comparison to other systems. Comparisons are being made among systems to determine how changes in fertilizer and herbicide management will affect water quality.

Tillage practices being studied at the research sites are shown in table 2. Each tillage practice represents a herbicide, fertilizer, and crop rotation typical for the area for the different climates and soils that exist at the various locations. Atrazine, alachlor, cyanazine, metribuzin, and metolachlor are the primary herbicides studied in the MSEA program. In some no-till systems, the postemergence herbicides imazethapyr and nicosulfuron are being applied for weed control. Several observations have been made from these farming practices.

Iowa studies revealed that surface runoff events shortly after application caused concentrations of atrazine and metolachlor to exceed 80 mg/L. But when surface runoff events did not occur until 60 days or later after application, no increase in stream concentrations were observed.

In many areas that are intensively tile-drained, atrazine moves to the tile through the soil profile. Concentrations increase in the tile drainage water with increased flow; however, the concentrations do not exceed 3 µg/L (fig. 2). The same concentration-flow relationship applied to a single field, a sub-basin of the Walnut Creek watershed, and the entire watershed.

Streamflow studies in Missouri showed that atrazine concentrations from the Goodwater Creek watershed vary over seasons, with the highest concentrations occurring during May and June as shown in figure 3. Some atrazine metabolites have been detected year-round.

Table 2. Tillage practices at MSEA research sites

Tillage Practice	Sites	Locations
Moldboard Plow	1	Nashua, IA
Chisel Plow	4	Nashua, IA Walnut Creek, IA Centralia, MO Piketon, OH
Ridge-Tillage	8	Treynor, IA Nashua, IA Walnut Creek, IA Princeton, MN Oakes, ND Piketon, OH Aurura, SD Arena, WI
No-Till	4	Nashua, IA Walnut Creek, IA Centralia, MO Piketon, OH
Disk and Till-Plant	1	Shelton, NE

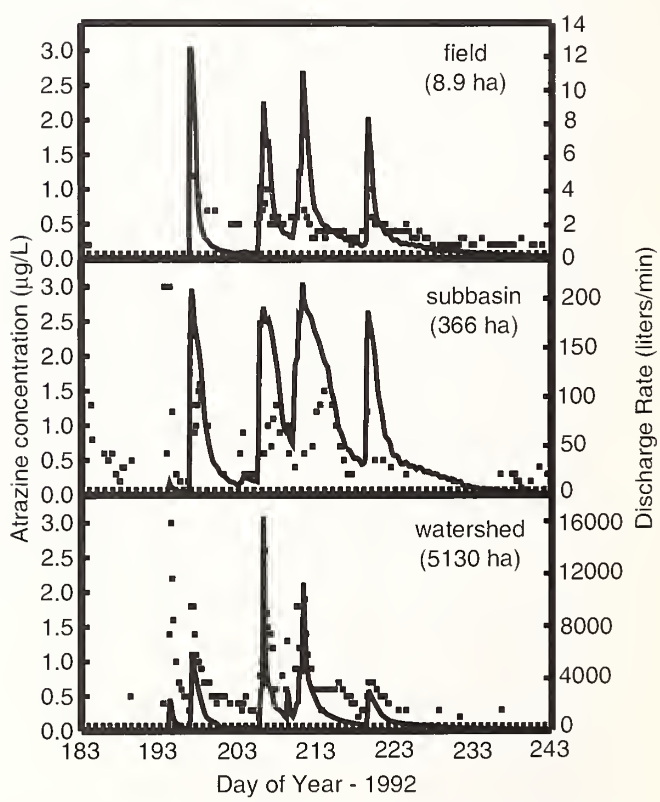


Figure 2. Atrazine concentrations (lines) versus discharge rates (squares) at three different sites (field, 8.9 ha; sub-basin, 366 ha; watershed stream channel, 5,130 ha) within Walnut Creek, Iowa, during July to August 1992.

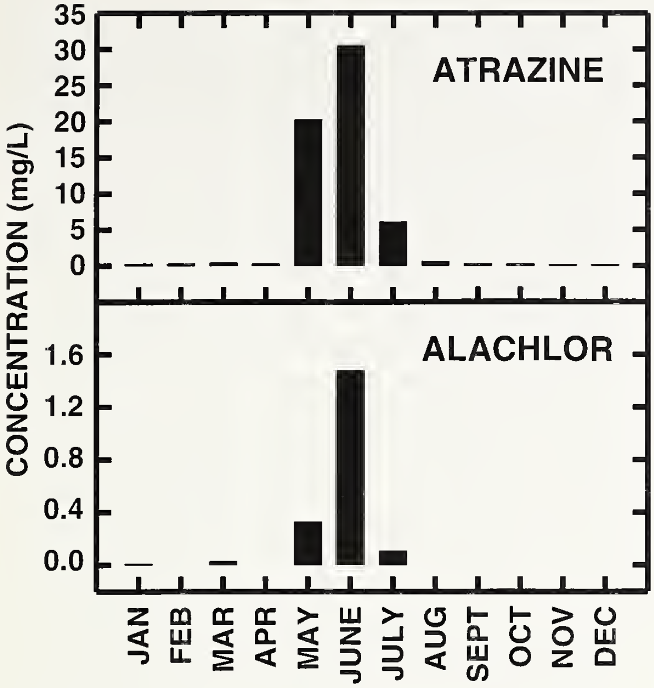


Figure 3. Mean monthly atrazine and alachlor concentrations in streamflow from Goodwater Creek, Missouri, in 1993.

Throughout the MSEA sites, the largest concentrations of herbicides are found in the upper 30 cm of the soil profile. The concentration gradients decrease with time during the growing season. A typical profile of the concentrations of atrazine within the upper meter of soil is shown in figure 4.

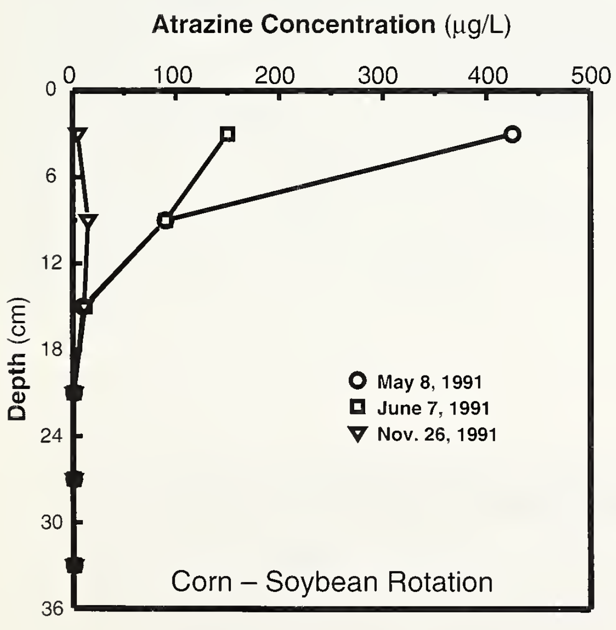


Figure 4. Atrazine concentrations within the soil profile at three sampling dates for Walnut Creek, Iowa.

Nitrate-nitrogen concentrations in the surface water decrease during runoff events. Concentrations of nitrate lost during runoff events in Iowa are less than 5 ppm.

Study of concentrations of atrazine, alachlor, and metolachlor in shallow wells placed under different farming systems revealed that soil profile characteristics are a dominant factor in determining the amount of herbicide below the root zone. In the glacial till soils of central Iowa, concentrations in the shallow wells (less than 10 m) were rarely above the detection limit. In the loess soils, with a more uniform soil profile, concentrations of metolachlor ranged between a nondetectable concentration to nearly 10 µg/L. In the sandy soils of the Anoka sand plain in Minnesota, concentrations of both alachlor and atrazine in ground water were below the quantitative reporting limit under both continuous corn and rotation field and sweet corn (fig. 5).

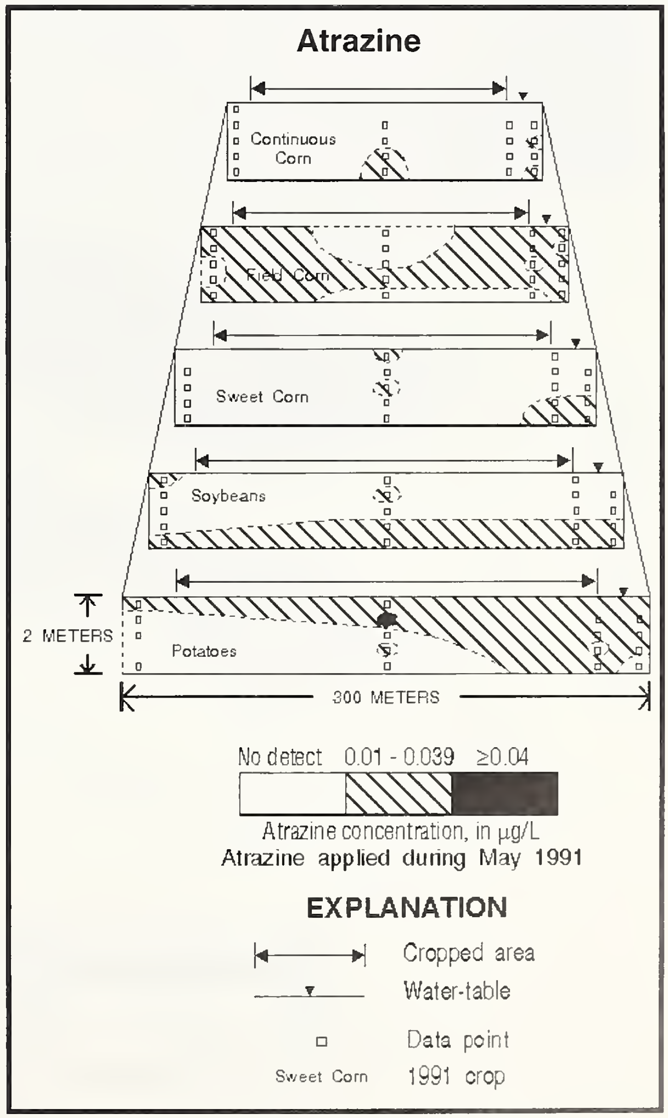


Figure 5. Atrazine concentrations within 2 meters below the surficial aquifer under fields of different crops in the Anoka sand plain of Minnesota.

A widespread sampling of 46 domestic wells, all deeper than 75 meters (250 feet), within the Walnut Creek watershed in Iowa showed no detectable amounts of atrazine, with nitrate-nitrogen concentrations of less than 2 mg/L.

Surface water samples collected at the outlet of the Walnut Creek watershed coupled with the quantity of water moving from the watershed have been used to calculate the load of atrazine and metolachlor. Less than 0.1 percent of the atrazine and metolachlor applied is lost from the watershed. Nitrate-nitrogen losses, however, can exceed 40 percent of the amount of nitrogen applied.

Sampling wells within the Platte River alluvium in Nebraska showed high concentrations of nitrate-nitrogen and atrazine under a continuous corn system with irrigation. Concentrations were typically above 30 mg/L of nitrate-nitrogen and often exceeded 3 μg/L for atrazine.

Coupled water and nitrogen management have decreased the atrazine concentrations in the ground water by 50 percent and decreased the nitrate-nitrogen concentrations in the root zone drainage from 11 mg/L to 2 mg/L in the July to mid-September period. The use of surge irrigation and other water and nitrogen management practices reduces potential leaching through the soil profile.

Missouri investigators found that hydrographs from ground water wells exhibit large spatial variability in response to recharge events, probably because of preferential flow through the claypan and fractures in the aquifer material. They also found that metabolites of atrazine and alachlor were more commonly detected (usually below 3 μg/L) than the parent compounds in the ground water samples. Ohio researchers found that water level rises immediately after precipitation events of greater than 25 mm (1 inch),

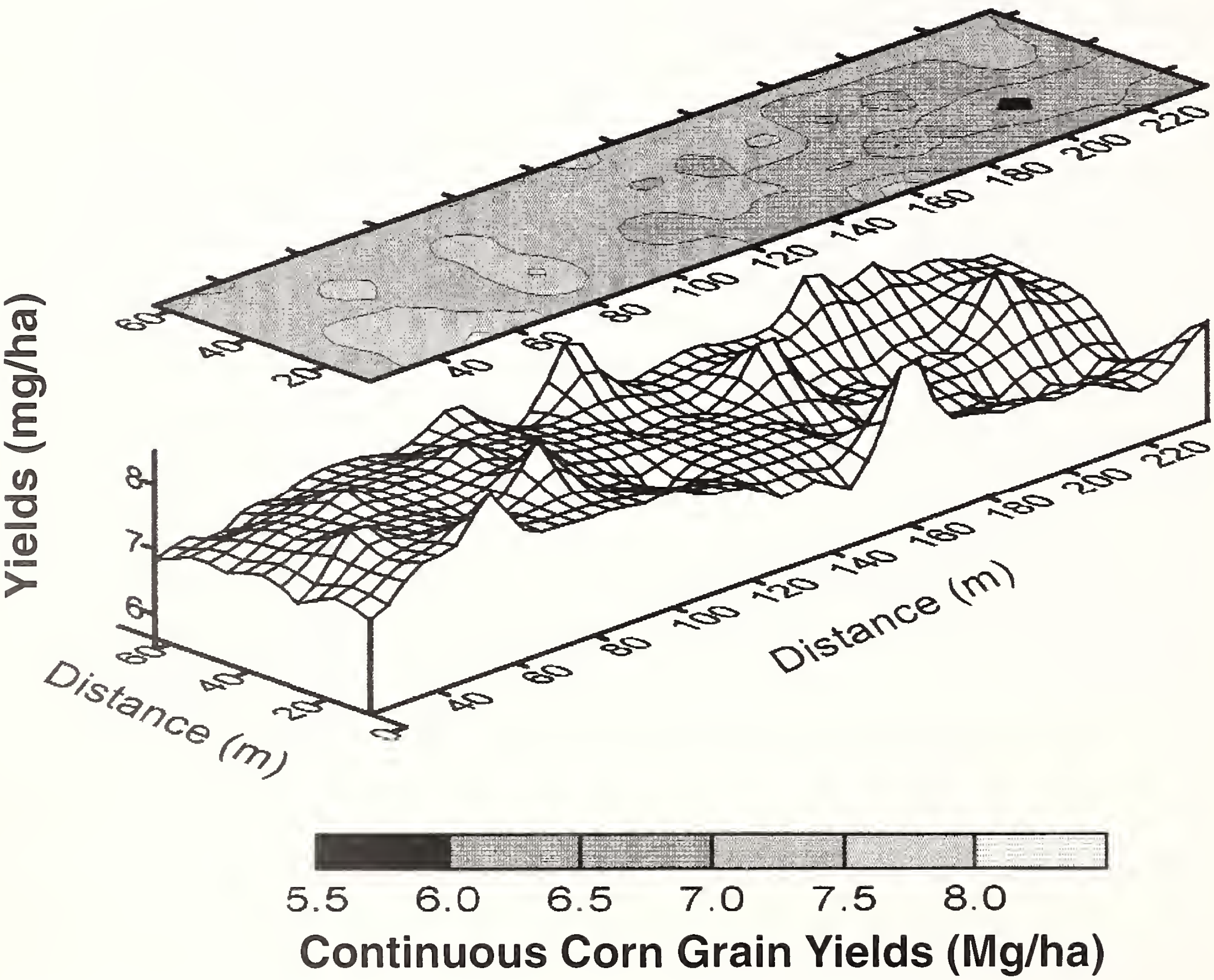


Figure 6. Variation of corn yield within a field on the Anoka sand plain at Princeton, Minnesota.

suggesting that part of the precipitation rapidly reached the water table as preferential flow. Flow reversals between the Scioto River and the alluvial valley have resulted in surface water moving into the aquifer at the Ohio site.

The parent compound, atrazine, has been detected in the tile drain lines shortly after rainfall events at Nashua, Iowa, suggesting that preferential flow through the root zone may be responsible for the rapid movement of herbicides within the root zone and leaching out of the root zone.

Water samples from wells in the Scioto River valley and in the Wisconsin glacial till and pre-Illinoian till in Walnut Creek, Iowa, indicate that nitrate concentrations are rapidly decreasing with depth. Denitrification is occurring within these geological units and may reduce potential nitrate loading of ground water.

Bromide tracers, used in Ohio to mimic nitrate and herbicide movement, indicate that movement in the soil-water zone is slow, partially as the result of drought conditions during the last 2 years. Slow rates of movement toward the water table allow for increased time for the degradation and adsorption processes to occur. Nitrate and herbicides detected in the wells within the Ohio study area are a result of past management practices.

Variation of yields within fields has been documented at all the sites. Results from Missouri showed that corn grain yields vary as much as 3.1 Mg/ha (50 bu/A) and soybeans vary as much as 1.7 Mg/ha (25 bu/A). These yield variations correlated with depth to the claypan. Results from Minnesota showed that corn yields varied by 15 percent over a 2-ha (4.4-A) field and the variations were related to nitrogen management and water stress. Variation of yields from fields in Iowa also show a large variation throughout the landscape and that the yield varies within a soil map unit as much as it does across a field. Variation of the yield within a section of a cornfield in Minnesota is shown in figure 6.

This combine harvesting corn at a Missouri site is linked to the satellite-based Global Positioning System to acquire data that will be correlated with soil samples taken earlier at sites throughout the field. This information will help growers plan optional fertilizer rates for the next crop (92BW1863-12).

Modifications in the Farming System

Changing the cultivation practice from chisel to ridge tillage increases the infiltration and reduces surface runoff. Surface runoff studies in Iowa show that there is less surface runoff and a reduced chance of herbicides being lost from systems with either ridge tillage or conservation tillage. Increased infiltration, however, can lead to increased leaching through the soil profile. Changing to ridge tillage does not increase herbicide concentration in the shallow wells but does increase the nitrate-nitrogen loads in the tile drainage in the shallow glacial till soils of northeastern Iowa and the loads in the seepage flow from the loess soils in southwestern Iowa.

Reducing the nitrogen input into the corn crop of the rotation and accounting for the nitrogen available from the soybean crop have led to a reduction in the nitrate levels in the shallow wells (Nebraska) and tile drains (Iowa) and to vulnerable shallow ground water at the Minnesota site characterized by rapid infiltration and coarse, sandy soils.

Banding herbicides in the ridge-tilled, corn-soybean rotation reduced total pounds of herbicide applications by two-thirds, compared to broadcast applications, with no atrazine or its metabolites, alachlor and metribuzin, reaching ground water under the coarse sandy soils at the Minnesota, North Dakota, and South Dakota sites.

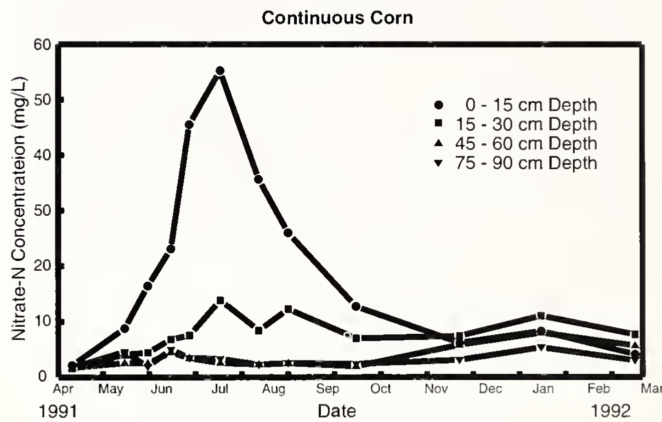
Knowledge of how variations in the claypan soil landscape in Missouri affect corn production has allowed for testing variable application of N fertilizer. With this approach, nitrate in the soil profile after corn harvest was reduced for less productive areas of the field.

Alternative Farming Practices

Alachlor (banded) and metribuzin (broadcast) in the alternative, sweet corn/potato farming system at the Minnesota site did not reach ground water. Alachlor did not move below the 75-cm (30-inch) depth and was never detected between the rows, while metribuzin remained in the 0 to 15 cm soil layer and was not detected after 5 weeks from application.

Reduced herbicide rates are being evaluated in a corn/soybean/wheat rotation system at the Ohio site. Information collected on weed control data has revealed that there are no differences in level of weed control even with a reduction in the herbicide rates.

Net use of applied N by the crop was greater in the ridge-tillage corn phase of the corn/soybean/wheat system in 1991, even though this system received less than half the amount of N applied than in the corn phase of the corn/soybean/wheat rotation with chisel-plow tillage. Seasonal variations in the nitrate concentrations within the root zone of the ridge-tillage and chisel plow treatments from Ohio are shown in figure 7.



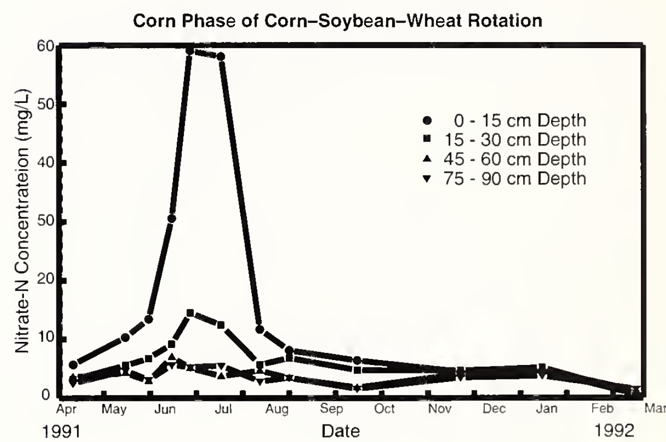


Figure 7. Monthly soil nitrate-nitrogen concentrations under corn in both corn-soybean-wheat and continuous corn rotations for Piketon, Ohio.

Nitrogen applications in the corn/soybean rotation or continuous corn had not affected ground water quality as of June 1993 at the Princeton, Minnesota, site. At the Arena, Wisconsin, site, efficiency of nitrogen use was improved by 5 percent in 1992 and 6 percent in 1993 by ridge-placed nitrogen. Results of application studies at Aurora, South Dakota, suggest that closing the slot created by fertilizer application in the ridge can reduce nitrate percolation to lower soil depths.

Introduction of strip cropping—narrow alternating strips of corn, soybeans, and oats—reduces the surface runoff of herbicides and leaching of nitrate, and increases the overall efficiency of production from the landscape.

In Ohio, no conclusive evidence was found that one management practice would result in less corn yield than another. In 1991, soybean yields on the ridge-tillage fields were lower than those on chisel-plowed fields; in 1992, there was no difference.

Production performanee of farming systems in Missouri was significantly affected by year-to-year variation in climate effects. No-till corn grain production and N-fertilizer-use efficiency were greatly improved by banding N fertilizers at planting. Surface application of soil-active herbicides without rain resulted in poor weed control and reduced grain yield.

New Farming Practices

Site-specific management

Reproducible estimates of site variability are required for site-specific management to maximize profitability while minimizing effects on water quality. At the Princeton, Minnesota, site, yield varied greatly across a 1.78-ha area. Nitrogen uptake and efficiency were correlated to grain yield in corn and soybeans. But nitrogen uptake and grain yield in 1993 did not spatially correlate well to uptake in 1992. In Missouri, noninvasive methods for mapping the depth to the claypan horizon are being investigated. Relative productivity within claypan fields has been linked to the topsoil depth above the elaypan. For site-specific management to become effective, there needs to be a better understanding of the variations of yield within fields.

Nitrogen-testing equipment

Relative nitrogen status (RNS) of the corn plants compared to those in a well-fertilized area was measured using a chlorophyll meter to assist in decisions about supplemental nitrogen fertilizer applications. In 1992, RNS did not decline below 69 until September, so no additional N was applied after the sidedress application. Corn yields in 1992 were 9.6 Mg/ha (153 bu/A) with 93 kg/ha (83 lb/A) of fertilizer N. In 1993, 13 kg/ha (12 lb/A) of N was applied through the irrigation system with yields of 8.4 Mg/ha (134 bu/A) with 130 kg/ha (116 lb/A) of fertilizer N.

Soil nitrogen availability as measured with the ion exchange membrane technique may have widespread application for farmers, extension agents, researchers, and commercial soil-testing firms. Ohio researchers have found that the ion exchange membrane technique can be used to provide estimation of nitrogen requirements, continuous monitoring of soil N processes, and risk assessment of ground water contamination.

Socio-Economic Studies on Farming Systems

Social attitudes and economics will affect whether farmers adopt practices and whether they are willing to experiment with changes within a farming system. A key component of the MSEA project has been the socio-economic studies conducted on the different farming systems.

Comparative economic analysis of the MSEA management systems in Ohio and Missouri has shown the corn-soybean system to be the most profitable and the corn-soybean-wheat system to be the least profitable, mainly because of the reduced income from the wheat phase of the rotation.

Continuous corn is not an economically viable crop for northeastern Iowa and is the most degrading to the water quality in the tile drains. This is because of the high use of nitrogen fertilizer and herbicides for corn production.

Adoption of improved water and nitrogen management practices in Nebraska will lead to a simultaneous increase in profit and reduction in ground water pollution.

At the start of the Northern Cornbelt Sand Plain Project, 50 percent of the Anoka sand plain growers were highly concerned about the effect of pesticides on water quality while 28 percent showed no concern. Thirty-six percent of the Anoka sand plain growers band-applied herbicides to corn and 20 percent to soybeans. But 60 percent of the growers were unaware of irrigation management techniques for this region.

Farmers within the Scioto River watershed are not particularly concerned about ground water pollution and are not adopting soil and ground water protection practices. These individuals do not perceive adoption of conservation practices to be in their best economic interests or effects on ground water to be of sufficient threat to warrant changes in production practices. But traditional approaches—for example, cost-sharing or incen-

tives to motivate landowners to adopt conservation practices—may not be successful in resolving ground water pollution problems.

Crop rotations are viewed as providing potential environmental benefits; however, before the MSEA program, there was little economic comparison of different cropping systems in the Midwest. Based on 2 years of data, the economic evaluation of the wheat/hairy vetch portion of the rotation system in Ohio reduced the expected return above variable costs of the corn-soybean-wheat system to $52.80/ha ($130.50/A) per year compared to $64.63/ha ($159.70/A) per year for the continuous corn system. The corn-soybean rotation return was $70.56/ha ($174.35/A) per year.

MSEA Findings

Results that can be put into practice from the MSEA program will affect both ground and surface water quality. MSEA researchers have worked to transfer the research from the plot and field studies into application on the farm and watershed levels. Several demonstration studies are under way at all sites to quickly place the latest scientific information in the hands of the farmer. Some of the common findings from the MSEA studies are listed below.

Complete understanding of herbicide movement and transformation within the root zone depends on soil characteristics, water content of the root zone, rainfall, tillage practices, and herbicide applied. These factors can be linked together to show that under proper management, herbicide losses rarely exceed quantitative reporting amounts. Information from the MSEA sites has shown that movement of herbicides associated with farming practices is not as large a problem as originally anticipated.

Use of ridge tillage with accompanying banding of herbicide in the row with sidedress nitrogen appears to reduce negative effects on ground water quality. As a guide to supplemental N applications, the chlorophyll meter shows promise for improving N efficiency, maintaining productivity, and reducing leaching in irrigated corn production.

Reduction in surface runoff from fields will improve surface water quality. Agricultural practices that reduce or retard offsite surface water movement minimize the risk of herbicide movement from the fields.

Increasing surface residue cover and the soil organic matter content appears to increase the degradation rates of herbicides. The increased degradation rates should decrease the potential leaching through the root zone.

Reduction in herbicide application rates may not translate into reduced weed control or reduced crop yields. Management of weed populations through scouting and proper selection of postemergence herbicides can reduce movement to ground and surface water.

Management of nitrogen fertilizer application through better understanding nitrogen dynamics within the soil and crop use patterns, both under irrigated and rainfed agriculture, will lead to improved efficiency of nitrogen use and reduced leaching below the root zone.

Mapping of yields along with the nutrient availability and other soil productivity factors within fields will provide the information needed for precision inputs of fertilizers and herbicides.

Conclusions

Advances being made on several fronts are improving our understanding of how current farming systems affect water quality. The MSEA program is rapidly developing a better understanding of how the corn-soybean rotation system affects water quality in different hydrogeological areas.

Modifications of tillage, herbicide, and nitrogen management within this system will lead to improved surface and ground water quality and more profitable systems. Alternative farming systems being developed will offer farmers a choice of profitable and environmentally sound systems for use in the Midwest.

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